

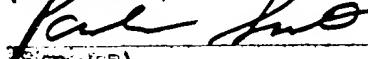
ISOLATED DIMERIC FIBROBLAST ACTIVATION  
PROTEIN ALPHA, AND USES THEREOF

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RELATED APPLICATION

This application is a continuation-in-part of Serial No. 08/230,491, filed April 20, 1994, now pending and incorporated by reference.

5

FIELD OF THE INVENTION

This invention relates to certain molecules associated with cancer tissues and reactive tumor stromal cells. More particularly, it relates to fibroblast activation protein alpha ("FAP $\alpha$ " hereafter) molecules. A monomeric form of the molecule has previously been identified immunochemically, but nucleic acid molecules coding for it had not been isolated or cloned nor have dimers been identified. These, *inter alia*, are features of the invention. The monomeric protein has a molecular weight of from about 88 to about 95 kilodaltons as determined by SDS-PAGE of boiled samples. The dimer has a molecular weight of about 170 kilodaltons as determined by SDS-PAGE of unboiled samples. FAP $\alpha$  is characterized by a number of features and properties which are shared by and characteristic of membrane bound enzymes, suggesting very strongly that it, too, is a membrane bound enzyme. The nucleic acid molecules, which are a key part of the invention, are useful both as probes for cells expressing FAP $\alpha$ , and as starting materials for recombinant production of the protein. The FAP $\alpha$  protein can then be used to produce monoclonal antibodies specific for the protein and are thus useful diagnostic agents themselves.

They also have additional uses, including uses related to enzymatic functions, as described herein.

BACKGROUND AND PRIOR ART

The invasive growth of epithelial cancers is associated with 5 characteristic cellular and molecular changes in the supporting stroma. For example, epithelial cancers induce the formation of tumor blood vessels, the recruitment of reactive tumor stromal fibroblasts, lymphoid and phagocytic infiltrates, the release of peptide mediators and proteolytic enzymes, and the production of 10 an altered extracellular matrix (ECM). See, e.g., Folkman, *Adv. Cancer Res.* 43: 175-203 (1985); Basset et al., *Nature* 348: 699-704 (1990); Denekamp et al., *Cancer Metastasis Rev.* 9: 267-282 (1990); Cullen et al., *Cancer Res.* 51: 4978-4985 (1991); Dvorak et al., *Cancer Cells* 3: 77-85 (1991); Liotta et al., *Cancer Res.* 51: 5054s- 15 5059s (1991); Garin-Chesa et al., *J. Histochem. Cytochem.* 37: 1767-1776 (1989). A highly consistent molecular trait of the stroma in several common histologic types of epithelial cancers is induction of the fibroblast activation protein (FAP $\alpha$ ), a cell surface glycoprotein with an observed  $M_r$  of 95,000 originally discovered 20 with a monoclonal antibody, mAb F19, raised against proliferating cultured fibroblasts. See Rettig et al., *Cancer Res.* 46: 6406-6412 (1986); Rettig et al., *Proc. Natl. Acad. Sci. USA* 85: 3110-3114 (1988); Garin-Chesa et al., *Proc. Natl. Acad. USA* 87: 7235-7239 (1990); Rettig et al., *Cancer Res.* 53: 3327-3335 (1993). Each of

these four papers is incorporated by reference in its entirety.

Immunohistochemical studies such as those cited supra have shown that FAP $\alpha$  is transiently expressed in certain normal fetal mesenchymal tissues but that normal adult tissues are generally FAP $\alpha$  $^-$ . Similarly, malignant epithelial, neural and hematopoietic cells are generally FAP $\alpha$  $^-$ . However, most of the common types of epithelial cancers, including >90% of breast, lung, skin, pancreas, and colorectal carcinomas, contain abundant FAP $\alpha$  $^+$  reactive stromal fibroblasts. Garin-Chesa et al., Proc. Natl. Acad. Sci. USA 87: 7235-7239 (1990). The FAP $\alpha$  $^+$  tumor stromal fibroblasts almost invariably accompany tumor blood vessels, forming a distinct cellular compartment interposed between the tumor capillary endothelium and the basal aspect of malignant epithelial cell clusters. While FAP $\alpha$  $^+$  stromal fibroblasts are found in both primary and metastatic carcinomas, benign and premalignant epithelial lesions, such as fibroadenomas of the breast and colorectal adenomas only rarely contain FAP $\alpha$  $^+$  stromal cells. In contrast to the stroma-specific localization of FAP $\alpha$  in epithelial neoplasms, FAP $\alpha$  is expressed in the malignant cells of a large proportion of bone and soft tissue sarcomas. (Rettig et al., Proc. Natl. Acad. Sci. USA 85: 3110-3114 (1988)). Finally, FAP $\alpha$  $^+$  fibroblasts have been detected in the granulation tissue of healing wounds (Garin-Chesa et al., supra). Based on the restricted distribution pattern of FAP $\alpha$  in normal tissues and its uniform expression in the supporting stroma of many epithelial cancers,

clinical trials with  $^{131}\text{I}$ -labeled mAb F19 have been initiated in patients with metastatic colon cancer (Welt et al., Proc. Am. Assoc. Cancer Res. 33: 319 (1992); Welt et al. J. Clin. Oncol. 12: 1561-1571 (1994)) to explore the concept of "tumor stromal targeting" for immunodetection and immunotherapy of epithelial cancers.

5 Rettig et al., Int. J. Cancer 58: 385-392 (1994), incorporated by reference, discusses the FAP $\alpha$  molecule and its features. Rettig et al postulate that FAP $\alpha$  is found in high molecular weight complexes in excess of 400 kilodaltons, but do not discuss the 10 possibility of dimeric molecules, nor does the paper elaborate on the specific enzymatic properties of the molecule.

15 The induction of FAP $\alpha^+$  fibroblasts at times and sites of tissue remodeling during fetal development, tissue repair, and carcinogenesis is consistent with a fundamental role for this molecule in normal fibroblast physiology. Thus, it is of interest and value to isolate and to clone nucleic acid molecules which code for this molecule. This is one aspect of the invention, which is described in detail together with other features of the invention, 20 in the disclosure which follows. Further aspects of the invention include the dimeric FAP $\alpha$  molecules, and the exploitation of the properties of these molecules. These features are also elaborated upon hereafter.

BRIEF DESCRIPTION OF THE FIGURES

Figure 1 compares the deduced amino acid sequence for FAP $\alpha$ , and the known sequence of CD26. The alignment has been optimized.

Figures 2A-2H, inclusive, display immunohistochemical detection of FAP $\alpha$  and CD26 in various tissues. In figures 2A and 2B, breast cancer is studied, for FAP $\alpha$  (figure 2A), and CD26 (figure 2B). In figures 2C and 2D, malignant fibrous histiocytoma is studied, for FAP $\alpha$  (figure 2C), and CD26 (figure 2D). Dermal scar tissue is examined in figures 2E (FAP $\alpha$ ), and 2F (CD26). Renal cell carcinoma is studied in figure 2G (FAP $\alpha$ ), and 2H (CD26).

Figure 3 presents some of the data generated in experiments which showed that FAP $\alpha$  had extracellular matrix (ECM) protein degrading activity. When zymographic detection of gelatin degrading extracts of 293-FAP was carried out, the active substance was found to have a molecular weight of about 170 kD, via SDS-PAGE, using unboiled samples to preserve enzyme activity.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTSExample 1

Fibroblast cell line WI-38 had been observed, previously, to react with mAb F19 (Rettig et al., Canc. Res. 46: 6406-6412 (1986); Rettig et al., Proc. Natl. Acad. USA 85: 3110-3114 (1988); Garin-Chesa et al., Proc. Natl. Acad. Sci. USA 87: 7235-7239 (1990);

Rettig et al., Canc. Res. 53: 3327-3335 (1993)). It was used in the experiments which follow.

A cDNA library was prepared from WI-38, using well known techniques and commercially available materials. Specifically, the 5 library was constructed in expression vector pCDNAI, using the Fast Track mRNA isolation kit, and Librarian cDNA phagemid system. Once the library was prepared, the vectors were electroporated into cell line E. coli MC 1061/P3. The pCDNAI expression vector contains an antibiotic resistance gene, so the E. coli were selected via 10 antibiotic resistance. The colonies which were resistant were then used in further experiments. The plasmid DNA from the colonies was obtained via alkaline lysis and purification on CsCl<sub>2</sub>, in accordance with Sambrook et al, Molecular Cloning: A Laboratory Manual (Cold Spring Harbor Lab, Cold Spring Harbor, N.Y. 2d Ed. 15 1989). The technique is well known to the art, but is incorporated by reference herein.

Once the plasmid DNA was isolated, it was used to transfect COS-1 cells, which were then cultured for forty-eight hours, after 20 which these were tested with antibody coated dishes. The mAbs used included F19, as described by Rettig et al., (1986), *supra*, which is incorporated by reference in its entirety. As COS-1 cells are normally FAP $\alpha^-$ , any positive results indicated the presence of the coding sequence. The immunoselection protocol was that of Aruffo et al., Proc. Natl. Acad. Sci USA 84: 3365-3369 (1987), 25 incorporated by reference herein.

Plasmid DNA from positive clones was recovered, in accordance with Hirt, J. Mol. Biol. 26: 365-369 (1967), reintroduced into E. coli MC 1061/P3, and reselected in COS-1 cells.

The protocol presented herein was followed for four rounds.

5 After this, the plasmid DNA of 50 isolated bacterial colonies was purified, using the Qiagen plasmid kit. Of the colonies, 27 clones were found to contain identical 2.8 kb inserts, as determined by EcoRI restriction enzyme mapping. Several of these were found to contain FAP $\alpha$ -specific cDNA as determined by transient expression  
10 in COS-1 cells and direct immunofluorescence staining with mAb F19. One of these clones, i.e., "pFAP.38" was selected for further study, as elaborated upon infra.

#### Example 2

15 Once pFAP.38 had been identified, it was tested together with a vector coding for known cell surface marker CD26 ("pCD26"), as well as with control vector pCDNA I.

In these experiments, COS-1 cells were transfected with one of pFAP.38, pCD26, or pCDNAI. After forty-eight hours, the transfectants were tested, using the well known MHA rosetting assay  
20 for cell surface antigen expression. In these experiments, mAb F19, which is FAP $\alpha$  specific, was used, together with mAb EF-1, which is CD26 specific. Also used were four other FAP $\alpha$  specific mAbs, i.e., FB23, FB52, FB58 and C48. Also tested were two cancer cell lines, which are known to react with mAb F19 (SW872  
25 liposarcoma), or EF-1 (SK-OV6 ovarian cancer). The results are set

forth in Table 1, which follows.

Table 1. Cell surface expression of multiple FAP $\alpha$  epitopes and CD26 in human cells and COS-1 cell transfectants

5	Target cell	Cell surface antigen expression				
		F19	FB23	FB52	FB58	C48
<u>10 Human cells</u>						
	SW872 liposarcoma	>95%	>95%	>95%	>95%	>95%
	SK-OV6 ovarian cancer	-	-	-	-	>95%
<u>15 COS-1 transfectants</u>						
	COS·pCDNA1 control	-	-	-	-	-
15	COS·pFAP 38	40%	30%	40%	20%	20%
	COS·pCD26	-	-	-	-	40%

Example 3

20 Immunoprecipitation studies were then carried out to identify the antigen being targeted by the antibodies.

Cells were metabolically labelled with Trans  $^{35}$ S-label, (ICN), extracted with lysis buffer (0.01 M Tris-HCl/0.15 M NaCl/0.01 M MgCl<sub>2</sub>/0.5% Nonidet P-40/aprotinin (20 ug/ml)/2 mM phenylmethylsulfonyl fluoride), and then immunoprecipitated. The protocols used are all well known, as will be seen by reference to Rettig et

al., Canc. Res. 53: 3327-3335 (1993); and Fellinger et al., Canc. Res. 51: 336-340 (1991), the disclosures of which are all incorporated by reference in their entirety. Precipitating mAbs were negative control mouse Ig, mAb F19, or EF-1. Control tests 5 were carried out with mock transfected COS-1 cells. Following immunoprecipitation, the immunoprecipitates were boiled in extraction buffer and separated by NaDODSO<sub>4</sub>/PAGE, under reducing conditions. In some experiments, an additional test was carried out to determine whether or not the immunoprecipitated material was 10 glycosylated. In these experiments, cell extracts were fractionated with Con A-SEPHAROSE prior to immunoprecipitation. Following immunoprecipitation, but prior to fractionation on NaDODSO<sub>4</sub>/PAGE, these precipitates were digested with N-Glycanase.

The results showed that, in COS-1 cells, pFAP.38 directs 15 expression of an 88 kd protein species (as determined via SDS-PAGE), which is slightly smaller than the 95 kd FAP $\alpha$  species produced by SW872, or cultured fibroblasts. Digestion with N-Glycanase produced peptides of comparable size (i.e., 74 kd versus 20 75 kd), showing that the glycosylation of the FAP $\alpha$  protein in COS-1 cells is different than in the human cell lines.

#### Example 4

Classic Northern blot analysis was then carried out, using the mRNA from FAP $\alpha^+$  fibroblast cell lines WI-38 and GM 05389, and FAP $\alpha^-$  ovarian cancer cell line SK-OV6. Using the procedures of Sambrook

et al., supra, five micrograms of mRNA from each cell line were tested. The probes used were <sup>32</sup>P labelled, and were prepared from a 2.3 kb ECO I fragment of pFAP.38, a 2.4 kb Hind III fragment of CD26, and a 1.8 kb BamHI fragment of  $\gamma$ -actin cDNA. These fragments 5 had been purified from 1% agarose gels.

The extracts of FAP $\alpha^+$  fibroblast strains showed a 2.8 kb FAP mRNA species, but extracts of SK-OV6 do not. A  $\gamma$ -actin mRNA species (1.8 kb), was observed in all species.

#### Example 5

10 The cDNA identified as coding for FAP $\alpha$  was subjected to more detailed analysis, starting with sequencing. The classic Sanger methodology, as set forth in Proc. Natl. Acad. Sci. USA 74: 5463-5467 (1977), was used to sequence both strands of the cDNA. Once this was secured, an amino acid sequence was deduced therefrom. 15 This information is presented in SEQ ID NO: 1. The sequence was then compared to the known amino acid sequence of CD26 (Morimoto et al., J. Immunol. 143: 3430-3437 (1989)). Figure 1 presents the comparison, using optimized sequence alignment. Any gaps in the comparison are indicated by asterisks, while identical amino acids 20 are shown by dashes in the CD26 sequence. A hydrophobic, putative transmembrane sequence is double underlined, while potential N-glycosylation sites are single underlined.

The sequence analysis shows a 2812 base pair insert, wherein 2277 base pairs constitute the open reading frame. This ORF

extends from start codon ATG at nucleotide 209, to stop codon TAA at 2486.

The deduced polypeptide is 760 amino acids long, and has a molecular weight of 87,832. In contrast, N-Glycanase digested, 5 immunopurified FAP $\alpha$  was reported to have an estimated  $M_r$  of 75,000 on NaDODSO<sub>4</sub>/PAGE (Rettig et al., Canc. Res. 53: 3327-3335 (1993)).

A GenBank data base search was carried out. The most closely related genes found were those encoding dipeptidyl peptidase iv homologues (DPPIV; EC 3.4.14.5), with human DPPIV (also known as 10 T-cell activation antigen CD26), showing 61% nucleotide sequence identity, and 48% amino acid sequence identity.

The second set of related genes are human, rat, and bovine homologues of DPPX, a gene of unknown function widely expressed in brain and other normal tissues. The predicted human DPPX gene 15 product shows about 30% amino acid sequence identity with FAP $\alpha$  and CD26. The FAP $\alpha$  molecule exhibits structural features typical of type II integral membrane proteins, including a large COOH-terminal extracellular domain, a hydrophobic transmembrane segment, and a short cytoplasmic tail. The putative extracellular domain contains 20 five potential N-glycosylation sites, eleven cysteine residues (eight of which are conserved between FAP $\alpha$  and CD26), and three segments corresponding to highly conserved catalytic domains characteristic of serine proteases, such as DPPIV. These conserved sequences are presented in Table 2, which follows. Comparisons to 25 DPPIV and DPPX were made via Morimoto et al., supra; Wada et al.,

Proc. Natl. Acad. Sci. USA 89: 197-201 (1992); Yokotani et al.,  
 Human Mol. Genet. 2: 1037-1039 (1993).

Table 2. Putative catalytic domains of FAP $\alpha$ , DPPIV and DPPX.

	624	702	734
Human FAP $\alpha$	....WGWSYGG.....	GTADDNV.....	DQNHGLS....
Human DPPIV	....WGWSYGG.....	GTADDNV.....	DEDHGIA....
Mouse DPPIV	....WGWSYGG.....	GTADDNV.....	DEDHGIA....
Rat DPPIV	....WGWSYGG.....	GTADDNV.....	DEDEHGIA....
Yeast DPPIV	....FGWSYGG.....	GTGDDNV.....	DSDHSIR....
Human DPPX	....FGKDYGG.....	PTADEKI...A...	DESHYFT....
Rat DPPX	....FGKDYGG.....	PTADEKI...A...	DESHYFH....
Bovine DPPX	....FGKDYGG.....	PTADEKI.....	DESHYFS....

Example 6

An additional set of experiments were carried out to determine whether FAP $\alpha$  related sequences are present in non-human species. To do so, human, mouse, and Chinese hamster genomic DNA was

digested using restriction enzymes, and tested, via Southern blotting, using the 2.3 kb fragment, labelled with  $^{32}\text{P}$ , describes supra. Hybridization was carried out using stringent washing conditions (0.1 x SSC, 0.1% NaDODSO<sub>4</sub>, 68°C). Cross-hybridization was readily observed with both the mouse and hamster DNA, suggesting the existence of highly conserved FAP $\alpha$  homologues. In control experiments using the CD26 cDNA fragment described supra, no evidence of cross hybridization was observed.

5  
10  
15  
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Example 7

The CD26 molecule shares a number of biochemical and serological properties with FAP $\beta$ , which is a previously described, FAP $\alpha$  associated molecule having a molecular weight of 105 kd, and is found on cultured fibroblasts and melanocytes (Rettig et al., Canc. Res. 53: 3327-3335 (1993)). Cotransfection experiments were carried out to determine whether FAP $\beta$  is a CD26 gene product. To test this, the same protocols were used which were used for transfection with pFAP.38 or pCD26, as described supra, but using the two vectors. The results presented supra showed that cotransfection efficiency was about 40% for each vector, so about 10-20% of cell should be cotransfected.

Following cotransfection, the COS-1 cells were Trans  $^{35}\text{S}$ -labeled, as described supra, then lysed, also as described supra.

The resulting cell extracts were separated on Con A SEPHAROSE, and the antigen (FAP $\alpha$  and/or CD26) were recovered in the Con A-

bound fraction. The bound fraction was eluted with 0.25 M  $\alpha$ -D-mannopyranoside. Immunoprecipitation was then carried out, as described supra, and the precipitates were separated on NaDODSO<sub>4</sub>/PAGE, also as discussed supra.

5        Those cells transfected only with pFAP.38 produced FAP $\alpha$ , but not FAP $\beta$  (determined from mAb F19 immunoprecipitates). They also produce no CD26 antigen (tested with EF-1). Those cells transfected with pCD26 alone produce CD26 but no FAP $\alpha$ .  
10      Cotransfectants produce CD26 and FAP $\alpha$ /FAP $\beta$  heteromers, as determined in the mAb F19 precipitates. This result provides direct evidence that FAP $\beta$  is a CD26 gene product.

#### Example 8

15      It has been observed previously that some cultured human cell types coexpress FAP $\alpha$  and CD26, and show FAP $\alpha$ /CD26 heteromer formation. In vivo distribution patterns of FAP $\alpha$  and CD26, however, as determined in previous immunohistochemical studies, appeared to be non-overlapping. (See Rettig et al., Proc. Natl. Acad. Sci. USA 85: 3110-3114 (1988); Garin-Chesa et al., Proc. Natl. Acad. Sci. USA 87: 7235-7329 (1990); Rettig et al., Canc. Res. 53: 3327-3335 (1993); Stein et al., in Knapp et al., eds. Leukocyte typing IV-white cell differentiation antigens, pp 412-415 (Oxford University Press, N.Y. 1989), pp. 412-415; Möbious et al., J. Exp. Immunol. 74: 431-437 (1988)). In view of the potential significance of FAP $\alpha$ /CD26 coassociation, tissue distribution was

reexamined, via side by side immunohistochemical staining of normal tissues and lesional tissues known to contain FAP $\alpha$ <sup>+</sup> fibroblasts or FAP $\alpha$ <sup>+</sup> malignant cells.

To test the samples, they were embedded in OCT compound, 5 frozen in isopentane precooled in liquid nitrogen, and stored at -70°C until used. Five micrometer thick sections were cut, mounted on poly-L-lysine coated slides, air dried, and fixed in cold acetone (4°C, for 10 minutes). The sections were then tested with mAbs (10-20 ug/ml), using the well known avidin-biotin immuno-peroxidase method, as described by, e.g., Garin-Chesa et al., J. Histochem. Cytochem. 37: 1767-1776 (1989); Garin-Chesa et al., Proc. Natl. Acad. Sci. USA 87: 7235-7239 (1990); Rettig et al., Canc. Res. 53: 3327-3335 (1993); Garin-Chesa et al., Am. J. Pathol. 142: 557-567.

15 The results are shown in figure 2. Breast, colorectal, pancreas and lung carcinomas showed strong expression of FAP $\alpha$  and no CD26 was found (see figures 2A and 2B). Five FAP $\alpha$ <sup>+</sup> sarcomas, including malignant fibrous histiocytoma (figures 2C and 2D), were tested, and there was no expression of CD26. Examination of 20 reactive fibroblasts of healing dermal wounds (figures 2E, 2F), showed abundant expression of both FAP $\alpha$  and CD26. The three renal carcinomas tested (figures 2G, 2H), showed expression of CD26 in malignant epithelium. FAP $\alpha$  was absent from malignant epithelial cells, and showed low expression in the stroma of these carcinomas.

Example 9

A mammalian cell line, transfected with a FAP $\alpha$  encoding cDNA, was prepared.

Human embryonic kidney cell line 293 is well known and widely available from, e.g., the American Type Culture Collection.

Samples of 293 were maintained, in an incubator, at 37°C, in an atmosphere of 95% air, and 5% CO<sub>2</sub>. The cells were cultured in a 50:50 mixture of Dulbecco's modified minimal essential medium and Ham's F12 medium, augmented with 10% fetal bovine serum, penicillin and streptomycin. Following the procedures described by Ustar et al., Eur. Mol. Biol. J. 1991, and/or Park et al., J. Biol. Chem. 169: 25646-25654 (1994), both of which are incorporated by reference, cDNA for FAP $\alpha$  (i.e., SEQ ID NO: 1), was transfected into the 293 cells. Details of the cDNA vector are provided, supra (pFAP.38). Transfectants were selected for resistance to antibiotics (200 ug/ml Geneticin), and were then maintained in selection medium, containing Geneticin.

Individual colonies of resistant cells were picked, grown to confluence in 6 well tissue culture plates, and were tested for FAP $\alpha$  expression in an immunofluorescence assay (IFA), using FAP $\alpha$  specific monoclonal antibody F19 as described supra.

Those colonies which expressed FAP $\alpha$  were expanded, and monitored by indirect IFA and cytofluorometric analysis, also as set forth, supra.

The IFAs were positive for the transfectants, referred to hereafter as cell line 293-FAP, but were negative for parental line 293.

Example 10

5 In order to confirm that recombinant FAP $\alpha$  was, in fact, being produced, a series of immunoprecipitation experiments were carried out. These followed the methods of Park, et al., supra, and Rettig et al., Canc. Res. 53: 3327-3335 (1993), both of which are incorporated by reference. Essentially,  $^{35}$ [S] methionine labelled 10 cell extracts were combined with monoclonal antibody F19, in the manner described supra. Precipitates were then boiled in extraction buffer and run on SDS-PAGE gels, using, as a negative control, mouse IgG1. Both cell line 293-FAP, and non transfected line 293 were tested. The results indicated clearly, that 15 recombinant FAP $\alpha$  was produced by the transfected cell line 293-FAP. This was determined by immunoprecipitation analyses, using FAP $\alpha$  specific monoclonal antibody F19.

Example 11

20 The ability to produce recombinant FAP $\alpha$  permitted further study of the molecule's properties. Specifically, given the structural features outlined in the prior examples, experiments were designed to determine if FAP $\alpha$  possesses enzymatic activities. The experiments were designed to test whether or not FAP $\alpha$  had

extracellular matrix (ECM) protein degrading activity.

Extracts of 293-FAP cells were prepared, using an extraction buffer (0.15M NaCl, 0.05M Tris-HCl, pH 7.4, 10 mM MgCl<sub>2</sub>, 1 percent Triton X-114), were cleared by centrifugation (4,000xg, 10 minutes at 4°C), and phase partitioned at 37°C for 10-20 minutes. This was followed by further centrifugation (4000xg, 20 minutes at 20-25°C). Detergent phases were diluted with buffer (0.15 M NaCl, 0.05 M Tris-HCl pH 7.4, 5 mM CaCl<sub>2</sub>, 5 mM MgCl<sub>2</sub>, 0.75% Empigen BB), and separated on concanavalin A-Sepharose following Rettig et al., supra. Any concanavalin A bound fractions were eluted with 0.25M methyl- $\alpha$ -D-mannopyranoside in elution buffer 0.15 M NaCl, 0.05 M Tris-HCl, pH 7.4, 5mM CaCl<sub>2</sub>, 5 mM MgCl<sub>2</sub>, 0.1% Triton X-100), mixed with zymography sample buffer (0.25 M Tris-HCl, pH 6.8, 8% SDS, 40% glycerol, 0.01% bromophenol blue), at a 3:1 ratio, and used for further analysis.

Aliquots of sample were loaded onto polyacrylamide gels containing 0.1% of either of gelatin or casein. Electrophoresis was then carried out in a Biorad Mini-Protein II system, at 20 mA constant current for 1.5 - 2 hours, until the bromophenol blue ~~due~~ fronts of samples had reached the lower end of the gel. The gel was removed and incubated for one hour at 20-25°C in a 2.5% aqueous solution of Triton X-100 on a rotary shaker. The Triton X-100 solution was decanted, and replaced with enzyme buffer (0.05M Tris-HCl, pH 7.5, 0.2M NaCl, 5 mM CaCl<sub>2</sub>, 5 mM MgCl<sub>2</sub>, 0.02% Brij 35). The gel was then incubated at 37°C or 41°C, followed by staining or

destaining at room temperature. Gels were stained with 0.5% of Coomassie Brilliant Blue G-250 in an aqueous solution of 30% methanol and 10% acetic acid for 15, 30, and 60 minutes, respectively. Subsequently, gels were incubated for 15 minutes in an aqueous solution of 30% CH<sub>3</sub>OH and 5% glycerol, followed by 5 drying between sheets of cellophane.

Gelatinase activity was evaluated in accordance with Kleiner et al., Anal. Biochem. 218: 325-329 (1994), incorporated by reference in its entirety. This is a routine assay used to 10 determine whether or not a protease capable of digesting gelatin is present. Labelled molecular weight standard were run on the same gels, under reducing conditions, for molecular weight determinations.

15 Proteolytic activity for defined amino acid sequence motifs were tested, using a well known membrane overlay assay. See Smith et al, Histochem. J. 24(9): 637-647 (1992), incorporated by reference. Substrates were Ala-Pro-7-amino-4-trifluoromethyl coumarin, Gly-Pro-7-amino-4-trifluoromethyl coumarin, and Lys-Pro-7-amino-4-trifluoromethyl coumarin.

20 The results of these experiments are depicted, in part, in figure 3. This figure shows zymographic detection of gelatin degrading activity, in the cell extracts. See Kleiner et al., supra. A protein species of approximately 170 kilodaltons, as determined by SDS-PAGE, was observed to have gelatin degrading 25 activity. This species, which was found in the 293-FAP cell line,

but not in untransfected 293 cells, is thus identified as FAP $\alpha$ . The molecular weight is consistent with a dimer, i.e., a dimeric FAP $\alpha$  molecule.

5 The proteolytic activity described herein where gelatin is the substrate, was not observed when casein was the substrate.

Example 12

Further studies were then undertaken in order to characterize the 170 kD FAP $\alpha$  dimer further. Specifically, the experiments described in example 11 were repeated, except that 5% of 2-mercaptoethanol or 5  $\mu$ m iodoacetamide was added to the extracts prior to SDS-PAGE, or ethylenediamine N,N,N',N'-tetraacetic acid (10 mM) was added to the incubation buffer used for gelatin zymography. None of these treatments abolished the enzymatic activity. In contrast, heating at 100°C for five minutes prior to SDS-polyacrylamide gel electrophoresis abolished the gelatin-degrading activity.

20 Further work, using a membrane overlay assay, described by, e.g., Smith et al., Histochem J. 24(9): 643-647 (1992), incorporated by reference, revealed that the FAP $\alpha$  dimers were able to cleave all of the Ala-Pro, Gly-Pro, and Lys-Pro dipeptides tested.

25 In further experiments, a fusion protein was produced which comprised the extracellular domains of both FAP $\alpha$  and murine CD8 proteins. This chimeric protein was produced in a baculovirus system in insect cells. The chimeric protein exhibited the same

enzymatic activity as FAP $\alpha$ , using the model discussed supra.

5 The foregoing examples describe an isolated nucleic acid molecule which codes for fibroblast activating protein alpha ("FAP $\alpha$ "), as well as dimeric forms of the molecule, and uses thereof. The expression product of the sequence in COS-1 is a protein which, on SDS-PAGE of boiled samples, shows a molecular weight of about 88 kd. Deduced amino acid sequence, as provided in SEQ ID NO: 1, for one form of the molecule, yields a molecular weight of about 88 kd.

10 It should be noted that there is an apparent discrepancy in molecular weight in that the COS-1 isolate is glycosylated, while molecular weight from deduced amino acid sequences does not account for glycosylation. Membrane proteins are known to exhibit aberrant migration in gel systems, however, which may explain the difference  
15 observed here.

Also a part of the invention are chimeric and fusion proteins, which comprise a portion of FAP $\alpha$  which contain the molecule's catalytic domain, and additional, non FAP $\alpha$  components. The FAP $\alpha$  catalytic domain per se is also a part of the invention.

20 It is to be understood that, as described, FAP $\alpha$  may be glycosylated, with the type and amount of glycosylation varying, depending upon the type of cell expressing the molecule. The experiment described herein shows this. This is also true for the dimeric form of the molecule, first described herein, having a  
25 molecular weight of about 170 kilodaltons as determined by SDS-PAGE of unboiled samples.

The invention also comprehends the production of expression vectors useful in producing the FAP $\alpha$  molecule. In their broadest aspect, these vectors comprise the entire FAP $\alpha$  coding sequence or portions thereof, operably linked to a promoter. Additional elements may be a part of the expression vector, such as protein domains fused to the FAP $\alpha$  protein or protein portions ("fusion protein") genes which confer antibiotic resistance, amplifiable genes, and so forth.

5 The coding sequences and vectors may also be used to prepare cell lines, wherein the coding sequence or expression vector is used to transfect or to transform a recipient host. The type of cell used may be prokaryotic, such as E. coli, or eukaryotes, such as yeast, CHO, COS, or other cell types.

10 The identification of nucleic acid molecules such as that set forth in SEQ ID NO: 1 also enables the artisan to identify and to isolate those nucleic acid molecules which hybridize to it under stringent conditions. "Stringent condition" as used herein, refers to those parameters set forth supra, whereby both murine and hamster sequences were also identified. It will be recognized by 15 the skilled artisan that these conditions afford a degree of stringency which can be achieved using parameters which vary from those recited. Such variance is apprehended by the expression 20 "stringent conditions".

25 The ability of nucleic acid molecules to hybridize to complementary molecules also enables the artisan to identify cells which express FAP $\alpha$ , via the use of a nucleic acid hybridization

assay. One may use the sequences described in the invention to hybridize to complementary sequences, and thus identify them. In this way, one can target mRNA, e.g., which is present in any cell expressing the FAP $\alpha$  molecule.

5 It is of course understood that the nucleic acid molecules of the invention are also useful in the production of recombinant FAP $\alpha$ , in both monomeric and dimeric form. The examples clearly show that host cells are capable of assembling the dimeric forms. The recombinant protein may be used, e.g., as a source of an 10 immunogen for generation of antibodies akin to known mAb F19, and with the same uses. Similarly, the recombinant protein, and/or cells which express the molecule on their surface, may be used in assays to determine antagonists, agonists, or other molecules which interact with the FAP $\alpha$  molecule. Such molecules may be, but are 15 not necessarily limited to, substrates, inhibiting molecules, antibodies, and so forth. This last feature of the invention should be considered in light of the observed structural resemblances to membrane bound enzymes. This type of molecule is associated with certain properties which need not be described in 20 detail here. It will suffice to say that inhibition or potentiation of these properties as associated with FAP $\alpha$  is a feature of this invention. For example, one may identify substrates or the substrate for FAP $\alpha$  molecules, via the use of recombinant cells or recombinant FAP $\alpha$  per se. The substrates can 25 be modified to improve their effect, to lessen their effect, or simply to label them with detectable signals so that they can be

used, e.g., to identify cells which express FAP $\alpha$ . Study of the interaction of substrate and FAP $\alpha$ , as well as that between FAP $\alpha$  and any molecule whatsoever, can be used to develop and/or to identify agonists and antagonists of the FAP $\alpha$  molecule.

5        Also a feature of the invention are isolated, dimeric FAP $\alpha$  molecules which have a molecular weight of about 170 kilodaltons as determined by SDS-PAGE, their use as an enzymatic cleaving agent, and other uses as are described herein. Enzymatically active forms of FAP $\alpha$  may also be produced as recombinant fusion proteins, comprising the catalytic domain of FAP $\alpha$  and other protein domains with suitable biochemical properties, including secretory signals protease cleavage sites, tags for purification, and other elements known to the artisan. The fact that FAP $\alpha$  has particular properties, as described herein, permits the identification of the 10 molecule on cells expressing them. In turn, because the FAP $\alpha$  molecule is associated with tumors and tumor stromal cells, targeting of FAP $\alpha$  with therapeutic agents serves as a way to treat 15 cancerous or precancerous condition, by administering sufficient therapeutic agent to alleviate cancer load.

20       The experiments showing the proteolytic properties of FAP $\alpha$  lead to yet a further aspect of the invention. It is well known that proteases which degrade extracellular matrix, or "ECM" proteins have an important role on certain aspects of tumor growth, including their effect on tumor cell invasion, tumor blood vessel 25 formation (i.e., neoangiogenesis), and tumor metastasis. Collagens are of special interest vis-a-vis the substrates of proteases, as

the collagens are an important part of the ECM. The fact that FAP $\alpha$  digests ECM suggests a therapeutic role for inhibitors of the molecule. "Inhibitors", as used herein, refers to molecules which interfere with FAP $\alpha$  enzyme function. Specifically excluded from such inhibitors is the monoclonal antibody F19. This mAb is known to bind to but not inhibit the enzyme function of FAP $\alpha$ , and hence it is not an inhibitor. The art is quite well versed with respect to monoclonal antibodies which both bind to and inhibit enzymes. Further examples of such inhibitors would include, e.g., substrate derivatives, such as modified collagen molecules, which interfere with the active site or sites of the FAP $\alpha$  molecule. Other suitable inhibitors will be apparent to the skilled artisan, and need not be listed here. In addition, the recombinant FAP $\alpha$  proteins and FAP $\alpha$ -transfected cell lines described supra can be employed in an enzymatic screening assay, using the substrate described supra or other suitable substrates, to identify inhibitors from any compound library.

Other aspects of the invention will be clear to the skilled artisan, and need not be set forth here.

The terms and expressions which have been employed are used as terms of description and not of limitation, and there is no intention in the use of such terms and expressions of excluding any equivalents of the features shown and described or portions thereof, it being recognized that various modifications are possible within the scope of the invention.